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Interaction of Shore-Parallel Geotextile Tubes and Beaches along the Upper Texas Coast

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PURPOSE: This Coastal and Hydraulic Engineering Technical Note (CHETN) summarizes initial lessons learned about ongoing field monitoring of shore-parallel geotextile tubes (GTs) constructed as beach dune cores in Galveston County, TX. Beach profile data and aerial photography collected between 1999 and 2007 are examined to evaluate the interaction of the GTs with beaches and the protection provided to public infrastructure and other landward improvements. Specific goals of the monitoring are to determine (a) if the GTs have exacerbated erosion of adjacent beaches by preventing release of littoral sediment or by increasing wave reflection and scour and (b) if GTs hinder post-storm beach recovery.

INTRODUCTION: Between April 1999 and May 2000, approximately 12 km of GT core dune projects were constructed along the Gulf of Mexico beaches of Galveston County. A major impetus for construction of the projects was the erosion caused by Tropical Storm (TS) Josephine in October 1996 and TS Frances in September 1998. TS Frances was particularly destructive, causing storm-surge flooding of as much as 1.8 m along the middle and upper Texas coast. The flooding persisted for about 48 hr, during which the elevated tides and waves caused severe erosion and damage to beach-front property. Hay-bale-reinforced dunes that had been constructed in 1997 along portions of the Galveston County shoreline were destroyed by TS Frances.

As a first step toward responding to the erosion caused by TS Frances, Galveston County obtained Federal disaster assistance to reconstruct dunes with GT cores to provide increased interim protection to primary evacuation routes and infrastructure landward of the dunes. Longer term solutions are also being sought through the Sabine Pass to Galveston Bay Shoreline Erosion Feasibility Study, which is a cost-sharing effort by Galveston County, Jefferson County, and the U.S. Army Corps of Engineers (USACE) and includes an offshore sand source investigation by the Texas General Land Office. Contract specifications for GTs are given in Jones et al. (2006).

DESCRIPTION OF SITE: Galveston County has approximately 85 km of Gulf shoreline along the upper Texas coast (Figure 1), with the northeastern 40 km consisting of Bolivar Peninsula and the southwestern 45 km consisting of Galveston Island. These two land masses are separated by the Galveston Entrance Channel, a natural inlet that has been modified by the construction of jetties and a Federally maintained deep-draft ship channel (Figure 2). Galveston Island is bordered on the southwest by San Luis Pass, a natural tidal inlet. A third inlet, Rollover Pass, is a mechanically cut inlet located near the northeastern end of Bolivar Peninsula constructed in 1955 to promote water exchange between Galveston Bay and the Gulf of Mexico.

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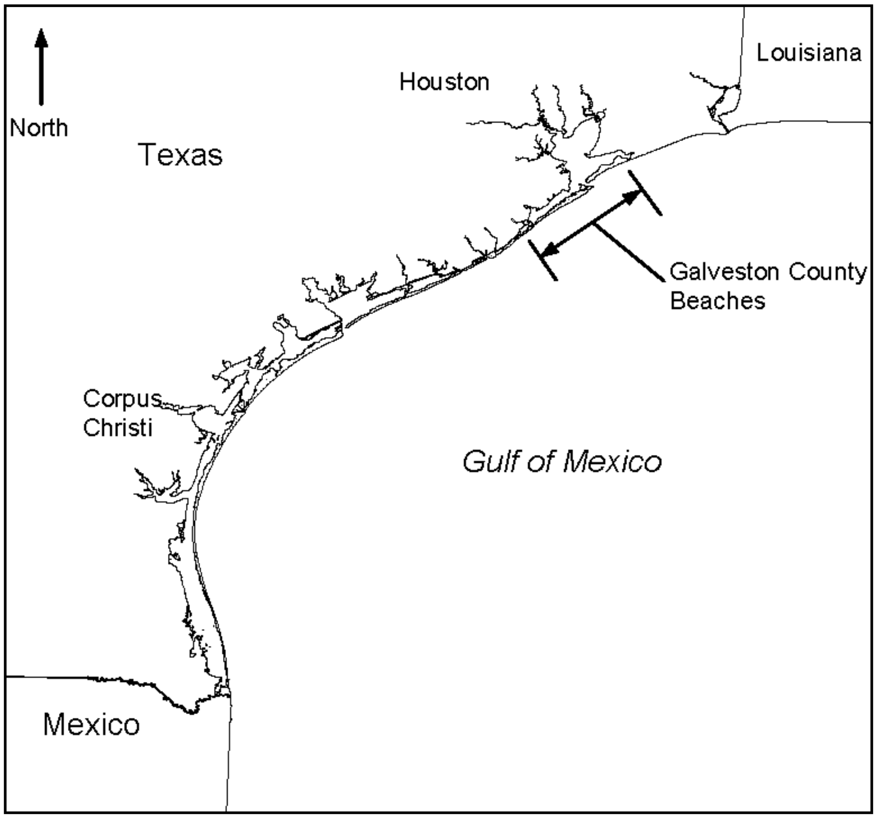

Figure 1. Project vicinity map.

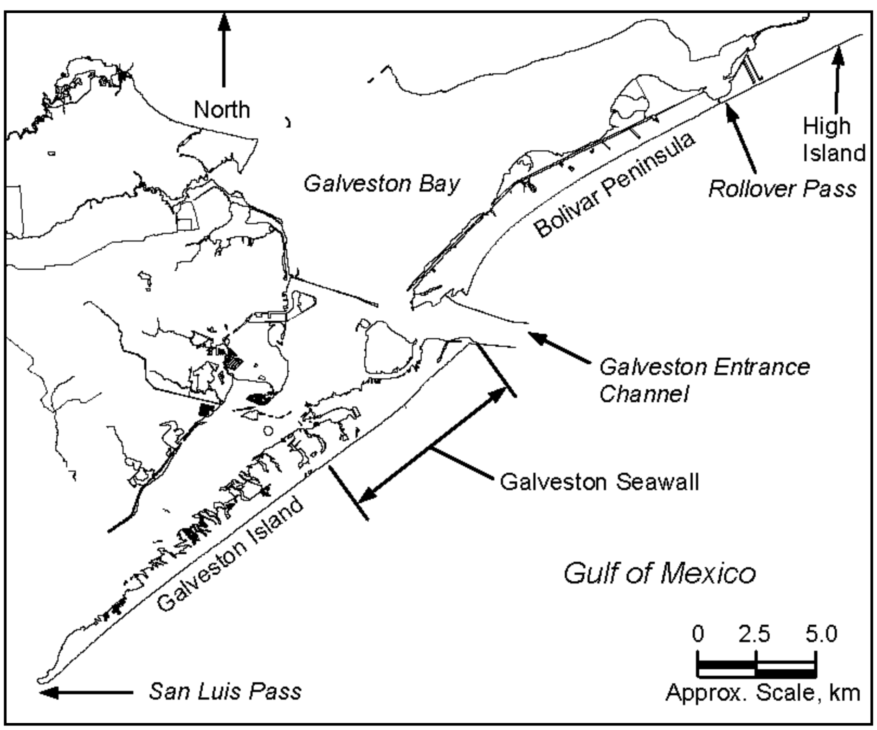

Figure 2. Project location map.

As described by Morton (1997), the eastern portion of Bolivar Peninsula (northeast of Rollover Pass) is part of a headland that is composed of predominantly cohesive sediment. Upper beaches are narrow, relatively steep, and covered by fine sand with patches of estuarine shells, rock fragments, and caliche nodules. Within the vicinity of Rollover Pass, the beach is backed by an erosional bluff extending to about 1.8 m in height. West of Rollover Pass, the beaches generally become broader and more sand rich, with the undeveloped beaches backed by dunes or a small scarp. The eastern approximate 16 km of Galveston Island is protected by a large concrete seawall, with approximately 5.8 km of the seawall containing a groin field. Beaches west of the seawall are sandy with small dunes that, due to ongoing erosion, are intermittently interrupted by houses and infrastructure.

At present, long-term shoreline change along Bolivar Peninsula and Galveston Island is controlled primarily by a limited sediment supply, tropical cyclones, and relative sea level rise. Along the upper Texas coast, long-term erosion is found because no sand has been delivered to this coastal area during Holocene sea level rise and still-stand. Locally, sediment is supplied as material transported alongshore from updrift eroding beaches. Excluding the impoundment area adjacent to the east jetty at the Galveston Entrance Channel, the beaches along Bolivar Peninsula are eroding at an average rate of about 1.5 m/year (Morton 1997). The beaches west of the Galveston seawall are eroding at an average rate of about 1.5 to 4.6 m/year, with rates generally decreasing with distance to the west (Morton 1997). Along the upper Texas coast, the direction of net longshore sediment transport is westward, except near the east end of Galveston Island, where a divergent nodal area is believed to exist due to wave sheltering by the relic ebb tidal shoal and jetties.

PROJECT BACKGROUND: Between April 1999 and May 2000, seven GT core dune projects were constructed in Galveston County, with 3,260 m on west Galveston Island and 8,260 m on Bolivar Peninsula. The projects consisted of the placement of 9-m circumference GTs generally at the approximate +1.5 m North American Vertical Datum of 1988 (NAVD) contour, with the GTs being filled and encased with sand hauled from upland borrow pits. Final height of the restored dunes generally ranged from 1.8 to 2.7 m. A typical cross section of a GT core dune is shown in Figure 3. For a more detailed discussion of GTs and their various coastal applications, refer to Pilarczyk (2000).

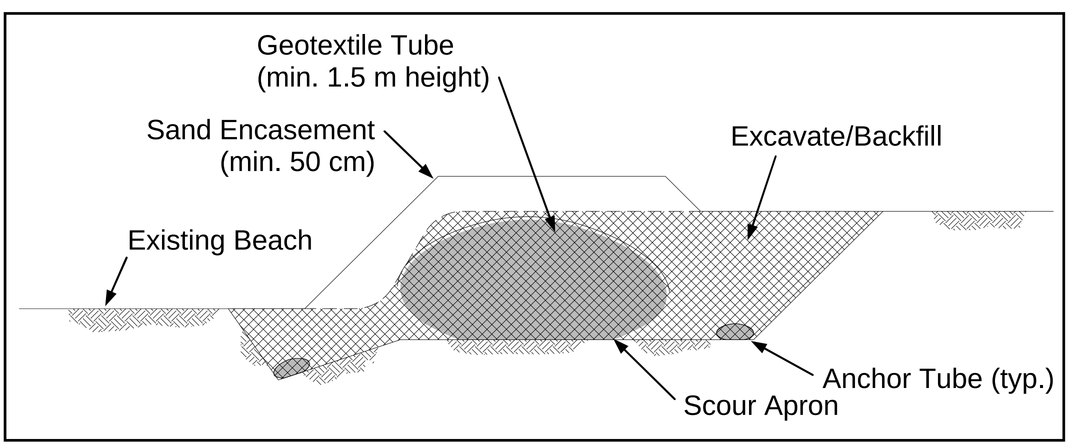

Figure 3. Typical section of GT core dune.

Prior erosion and physical obstructions such as houses prevented location of the GTs within existing dunes or at the same base elevation as natural dunes, which have a toe elevation of about +1.8 m NAVD. To determine an adequate alternative base elevation for the GTs, calculations of wave runup were performed based on the method presented in USACE (1990). Input for the runup calculations included tide data collected at the Galveston Pleasure Pier by the National Oceanic and Atmospheric Administration (NOAA) and wave data collected by NOAA at National Data Buoy Center (NDBC) sta 42035. This analysis resulted in selection of a minimum target elevation of +1.2 m NAVD for the base of the GTs. Based on the runup calculations, it was estimated that the GTs would be impacted by waves on average about 130 hr/year, and the sand cover would likely require partial or full replacement on an annual basis. The frequency of wave impact was expected to increase as ongoing shoreline recession continued and the beaches fronting the GTs narrowed.

Wading-depth beach profile data and aerial photographs were collected for the design of each of the individual GT projects. In addition, coastal boundary surveys were conducted at west Galveston Island in August 1999 and at Bolivar Peninsula in May–July 1999 and May 2000. The coastal boundary surveys are useful in that they provide near-synoptic coverage for larger areas in contrast to the more localized, project-specific coverage provided by the individual pre-design surveys.

Between 1999 and 2007, various beach nourishment and dune restoration projects occurred at both GT and non-GT locations. These projects added approximately 1,400,000 m^3 of sand at Bolivar Peninsula and 360,000 m^3 of sand at west Galveston Island (HDR | Shiner Moseley 2007). Many of these projects were either dune restoration or relatively small veneer fill placements that added sand only to emergent portions of the beach.

Since spring 2003, annual wading-depth beach profile surveys have been conducted at the GT locations and within adjacent control areas on west Galveston Island and Bolivar Peninsula. Additional surveys were conducted following major storms to assess erosion and beach recovery. For all surveys, transects were generally spaced 150 m alongshore and extended across shore to at least the -0.6 m NAVD contour.

STORM ACTIVITY: Although the Texas coast is characterized by a milder wave climate than the Atlantic and Pacific coasts of the United States, beach erosion rates are significant because of tropical cyclones combined with a lack of sand sources. Table 1 lists notable storms that caused storm surge along Galveston County beaches between October 1996 and October 2006.

To determine the potential for beach and dune erosion along Galveston County, Gibeaut and Gutierrez (1999) established threshold storm conditions beyond which they predicted significant erosion will occur. The threshold criteria are based on conditions experienced during TS Josephine and TS Frances and consider the water level (WL) measured at the Galveston Pleasure Pier and offshore significant wave height measured at NOAA sta 42035. According to Gibeaut and Gutierrez (1999), water level standard deviation (WLSD) measured at the Pleasure Pier can be applied as a proxy measure of wave energy in lieu of nearshore wave measurements. WLSD is calculated as the standard deviation of 181 1-sec readings (the average of these readings is the WL).

Table 1
Notable Tropical Cyclones (1996-2006)

Storm	Date	Peak Surge at Galveston Pleasure Pier, m (NAVD88)
TS[a] Josephine	October 1996	+1.3
TS Charley	August 1998	+0.9
TS Frances	September 1998	+1.6
TS Allison	June 2001	+1.1
TS Fay	September 2002	+1.3
HU Isidore	September 2002	+1.0
HU Lili	October 2002	+1.0
HU Claudette	July 2003	+2.1
TS Grace	September 2003	+0.9
TS Ivan	September 2004	+1.1
HU Dennis	July 2005	+0.8
HU Katrina	August 2005	+0.8
HU Rita	September 2005	+1.2
Unnamed Storm	October 2006	+1.4

[a] NOTE: TS denotes tropical storm; HU denotes hurricane.

The stated threshold conditions for significant erosion and vegetation line recession are a WL that exceeds +0.9 m mean sea level (+1.1 m NAVD) and a WLSD that exceeds 0.26 m for at least 12 hr. The WLSD value reportedly corresponds to offshore wave heights greater than 3 m. Large values for the product of WL and WLSD are stated to be indicators of periods of large waves coincident with high WL. Extreme conditions are defined as the product WL x WLSD that exceeds 0.41 m^2 (Gibeaut and Gutierrez 1999).

Although several of the storms that occurred after TS Frances did not meet the threshold conditions of Gibeaut and Gutierrez (1999), post-storm conditions observed at Galveston County beaches indicated that considerable erosion did occur. For example, in September 2002, the upper Texas coast was subjected to TS Fay, Hurricane (HU) Isidore, and HU Lili, with tides remaining above predicted levels for the entire month. In particular, TS Fay caused notable erosion to dunes and bluffs and damaged some of the GTs. Damage to GTs consisted primarily of tears due to differential settlement and/or rolling from scour, and punctures from wave-borne debris. In addition to the damage, most of the sand cover was lost. Damage to all GTs was repaired and sand cover replaced in the spring of 2003. For a more detailed description of GT failure mechanisms and repair procedures, see Heilman and Hauske (2003).

Hurricane Claudette made landfall as a strong Category 1 hurricane on 15 July 2003 at Matagorda Island approximately 180 km southwest of Galveston. Claudette caused shoreline recession in excess of 15 m in many locations within the monitoring areas and resulted in an estimated damage of $180 million along the Texas coast (Beven 2003). Observations and measurements within the monitoring areas indicated that significant erosion to the beaches and dunes as well as damage to some of the GTs had occurred. Fortunately, no houses within the monitoring areas were destroyed. However, many houses that were not protected by GTs were located seaward of the vegetation line (and thus on the public beach) following the storm.

As shown in Figures 4 and 5, HU Claudette met the threshold WL and wave height conditions described by Gibeaut and Gutierrez (1999). Also shown are WL and wave height during TS Frances in 1998 and HU Rita in 2005. Hurricane Claudette had the greatest peak water level and wave height, but TS Frances had the longest duration. Surprisingly, HU Claudette did not meet the threshold WLSD of 0.26 m for 12 hr, even though offshore wave heights were in excess of 3 m for approximately 24 hr. Figure 6 shows a comparison of HU Claudette to other storms (including those analyzed by Gibeaut et al. (2003)) based on the product of WL and WLSD. Note the low value for HU Claudette (less than the 0.41 m^2 threshold) despite the significant erosion that occurred. The low value for HU Claudette suggests that WL x WLSD may not be a reliable or sufficient measure of storm erosion potential.

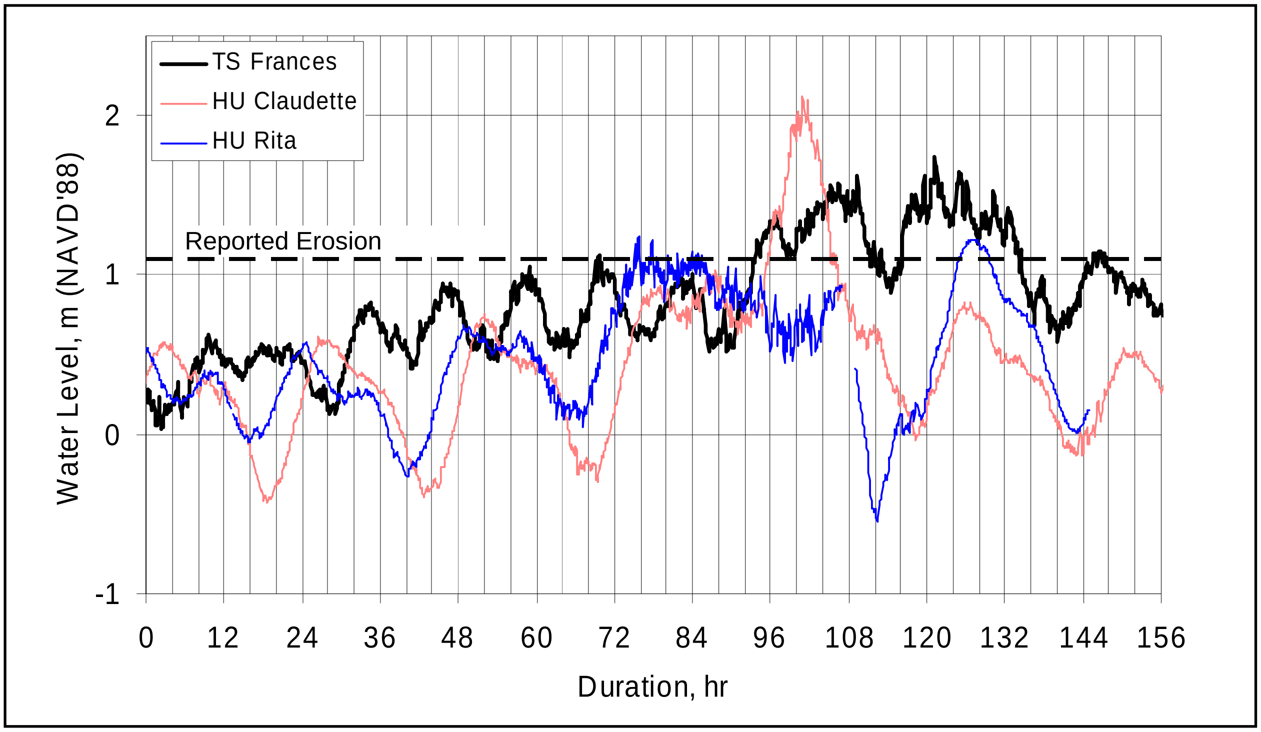

Figure 4. Water level records for Galveston Pleasure Pier.

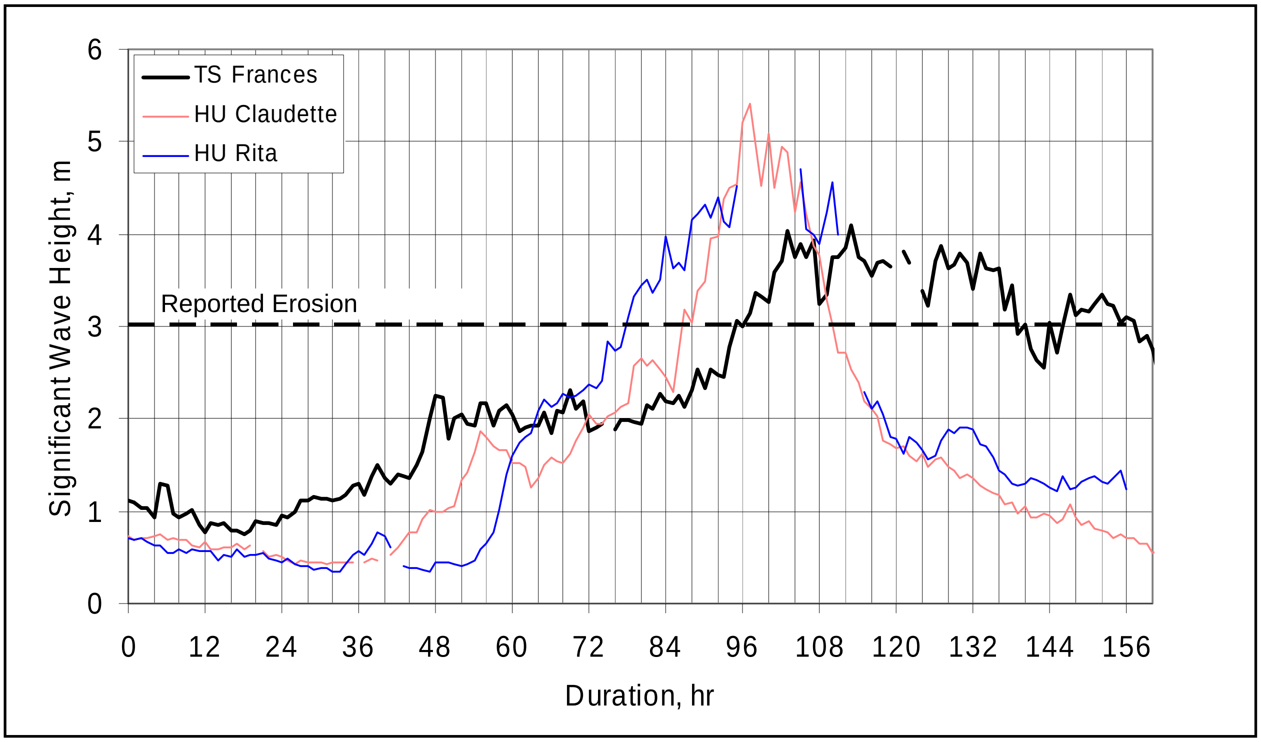

Figure 5. Significant wave height at NDBC sta 42035.

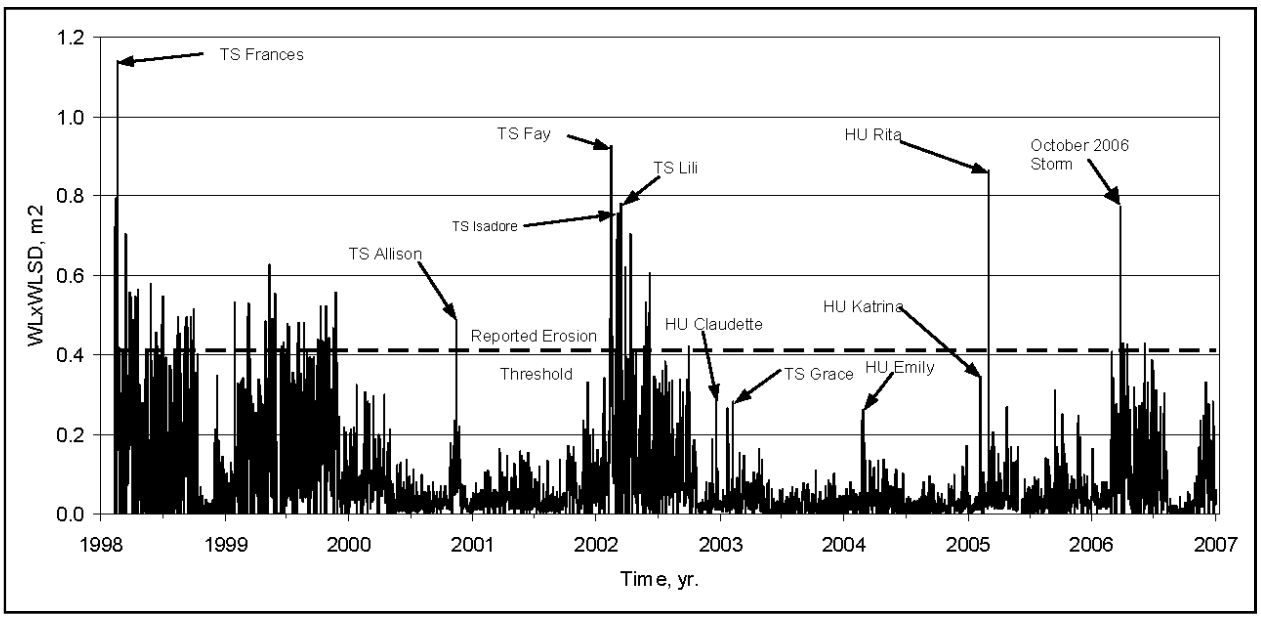

Figure 6. Product of water level (WL) and water level standard deviation (WLSD) from Galveston Pleasure Pier tide gauge (modified after Gibeaut et al. 2003).

PRIOR INVESTIGATIONS: Because GTs represent a relatively new approach for shoreline protection, few investigations have examined the interaction of shore-parallel GTs with beaches. The interaction of seawalls, revetments, and bulkheads with beaches has been studied more extensively, e.g., Kraus (1987, 1988), Morton (1988), USACE (1992, 1995), McDougal et al. (1996), Kraus and McDougal (1996), and Kraus and Heilman (1998). These and other studies suggest that the GTs in Galveston County could have the following potential impacts on the beach:

1. Storms may cause localized scour in front of and at the lateral ends of the GTs.
2. As ongoing shoreline recession continues, the dry-beach width in front of the GTs will decrease because the landward limit of the beach is held in place by the GTs. This process is often referred to as "passive erosion."
3. As beach width decreases, the natural geomorphology of the dry beach and dune system is altered.
4. As the beaches continue to erode, the GTs will contain sand on their landward side that would otherwise be transported to downdrift beaches or across shore. A parallel to this impact is the accelerated erosion west of the Galveston seawall. This is an example of "active erosion."
5. Increased erosion may also result in the GTs protruding into the surf zone and creating a partial barrier to longshore transport, trapping sand on their updrift side and accelerating erosion on their downdrift side. This impact is unlikely (or temporary) for GTs considering their limited life under continuous, long-term exposure to open-coast surf.
6. Societal impacts include adverse aesthetics and hindrance of beach access, especially if GTs remain uncovered after storms.

The most relevant and comprehensive investigations that focused specifically on GTs are the studies by Gibeaut et al. (2002, 2003), which present independent results of monitoring of the GT-core dune projects in Galveston County. Gibeaut et al. (2002, 2003) incorporated wading-depth beach profile surveys, light detection and ranging (LIDAR) surveys, and field observations to evaluate the condition of the GTs and their interaction with the beach. Key conclusions of these studies include the following:

1. The GTs will eventually fail if exposed to prolonged direct wave attack, making them useful only for protection against short-term or event-specific erosion.

2. Seasonal high tides and storms cause frequent loss of the sand placed to cover the GTs.

3. As of 2003, the GTs in Galveston County had not increased erosion rates at adjacent beaches.

ANALYSIS: To assess the interaction of the GTs with the beach, the beach profile data were analyzed to develop shoreline contours and to calculate rates of contour advance and recession at GT and non-GT (control) areas. Contour changes were evaluated over the approximate 8-year period since the GTs have been in place and a shorter period during which the GTs were impacted by the large waves and storm surge during HU Claudette.

Contours were selected that correspond with key physical features along the beach. The +1.8 m contour was selected as an approximation of the dune-bluff line, and, based on measurements by Gibeaut et al. (2002, 2003), the +0.76 m contour was selected as an approximation of the boundary between wet and dry sand as well as the seaward limit of the beach area where vehicles typically drive and park. Because analysis of lower (submerged) contours was limited by the surveys being restricted to wading depth, the seaward-most contour analyzed was -0.6 m. Comparing concurrent changes at higher and lower contours provided an indication of any redistribution of sand across shore (i.e., increase or decrease in shoreface slope).

The monitoring area on Galveston Island is located along 11.9 km of shoreline directly west of the Galveston Seawall. The GT project sites are located intermittently along this stretch of shoreline. Most of the project lengths are relatively small and typically front either a subdivision or public park. The monitoring area on Bolivar Peninsula is located along 11.3 km of shoreline centered at Rollover Pass. In contrast to the monitoring areas on Galveston Island, the GTs on Bolivar Peninsula are continuous within the central portion of the monitoring reach, with adjacent control areas located to the east and west.

Geotextile Tube and Beach Interaction from 1999/2000 to 2007: To evaluate the interaction of the GTs with beaches during the approximate 8 years since GT construction, the coastal boundary surveys performed in 1999 and 2000 were compared to the spring 2007 survey. Note that the coastal boundary surveys did not necessarily include control areas. Along Galveston Island, beach width (as delineated by the +0.76 m contour) was generally maintained or increased within both GT and control areas (Figure 7), largely a consequence of periodic small-scale beach nourishment. An exception was recession of up to 13 m (1.6 m/year) between sta 40+00 and 42+70, although the rate was significantly less than the long-term average recession of about 3.8 m/year documented by Morton (1997).

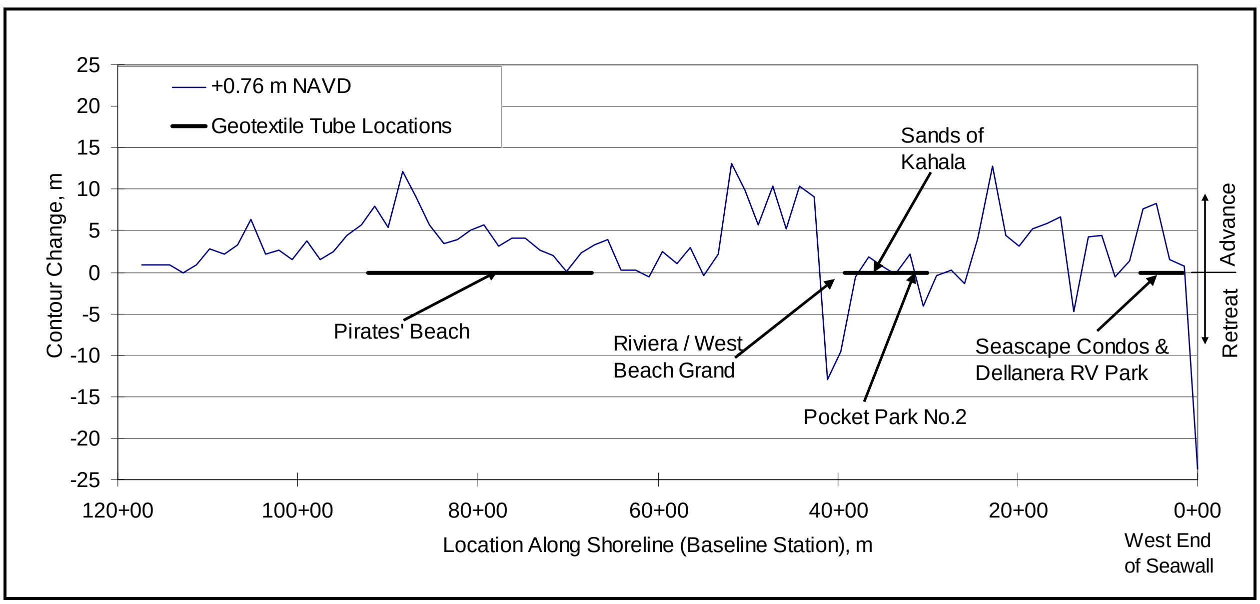

Figure 7. Contour change at Galveston Island, August 1999 to May 2007.

At Bolivar Peninsula, as much as 17 m (2.2 m/year) of advance occurred within a reach extending 2.7 km east and 1.2 km west of Rollover Pass (Figure 8), with recession directly west of Rollover Pass of up to 9.6 m (1.2 m/year). This reach has received regular beach nourishment totaling approximately 1,400,000 m^3 since 1999. To the east of this reach, recession of up to 13.7 m (1.7 m/year) occurred to the limit of the 1999 survey at Pelican Pier. To the west, recession of up to 6.2 m (0.8 m/year) occurred at approximately 1.8 km from Rollover Pass. The long-term average of recession for this reach documented by Morton (1997) is approximately 1.5 m/year.

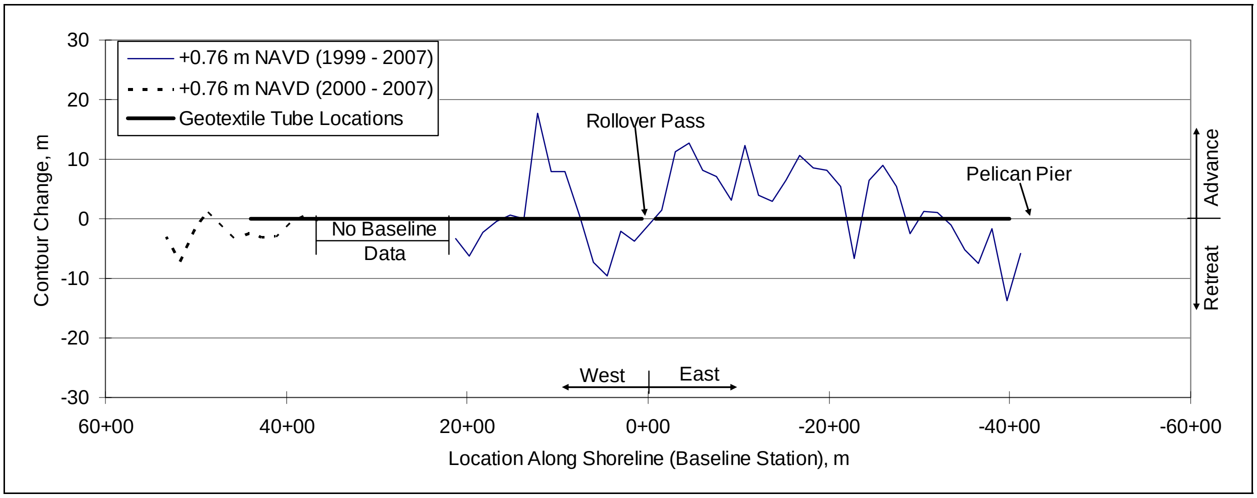

Figure 8. Contour change at Bolivar Peninsula, May-July 1999 and May 2000 to May 2007.

Geotextile Tube and Beach Interaction during HU Claudette: Comparison of surveys performed 3 months before and 3 weeks after HU Claudette revealed an overall recession of upper contours that was accompanied by an advance of lower contours along most of the study area (Figures 9 and 10). This process generally occurred within both GT and non-GT areas and is attributed to flattening of the beach profile as sand was transported seaward during the storm, causing the lower elevations, in particular the -0.6 m contour, to advance seaward. An exception is a reach on Bolivar Peninsula west of Rollover Pass between sta 18+00 and 37+00, which experienced nearly continuous recession of all contours.

The contour change shown for Galveston Island in Figure 9 may be misleading in appearing to indicate that, in response to HU Claudette, there was less recession of the +0.76 m contour within the GT area between sta 1+50 and 6+00 as compared with non-GT areas. This difference is attributed primarily to a beach nourishment project in June 2003, which placed 60,000 m^3 of sand within this reach. The beach nourishment translated the entire profile seaward and also provided additional sand to the upper portion of the profile for cross-shore transport. As a result, all contours within this area experienced advance that was greater than the subsequent recession during HU Claudette. The -0.6 m contour showed advances in excess of 30 m.

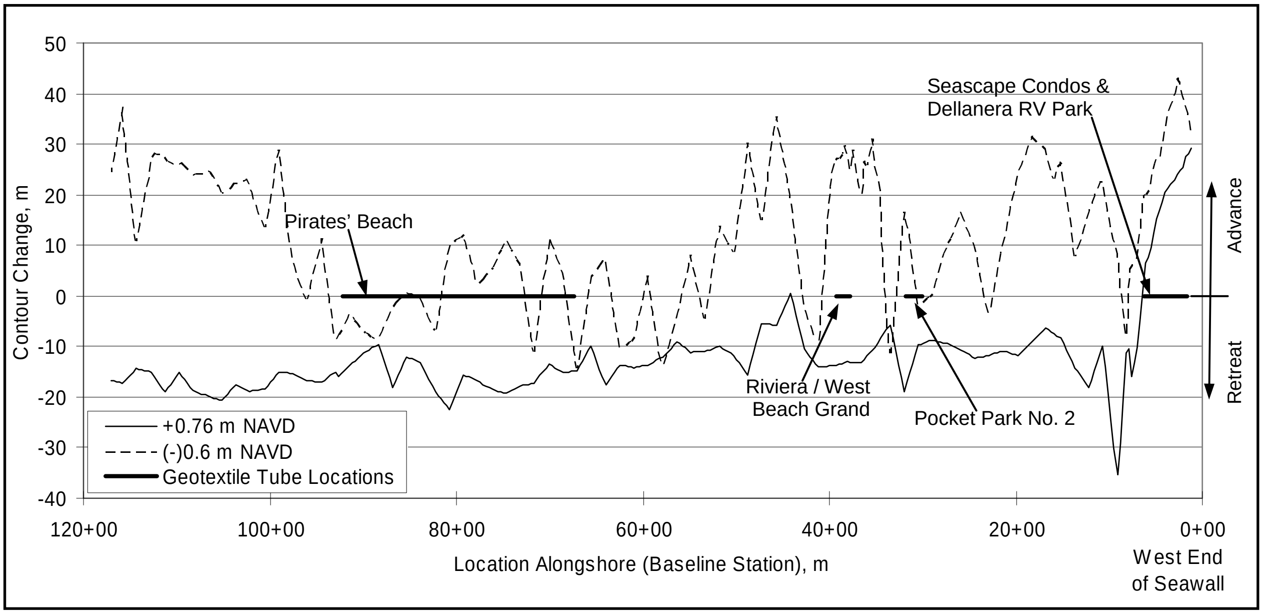

Figure 9. Contour changes at Galveston Island from HU Claudette (April 2003 to July 2003).

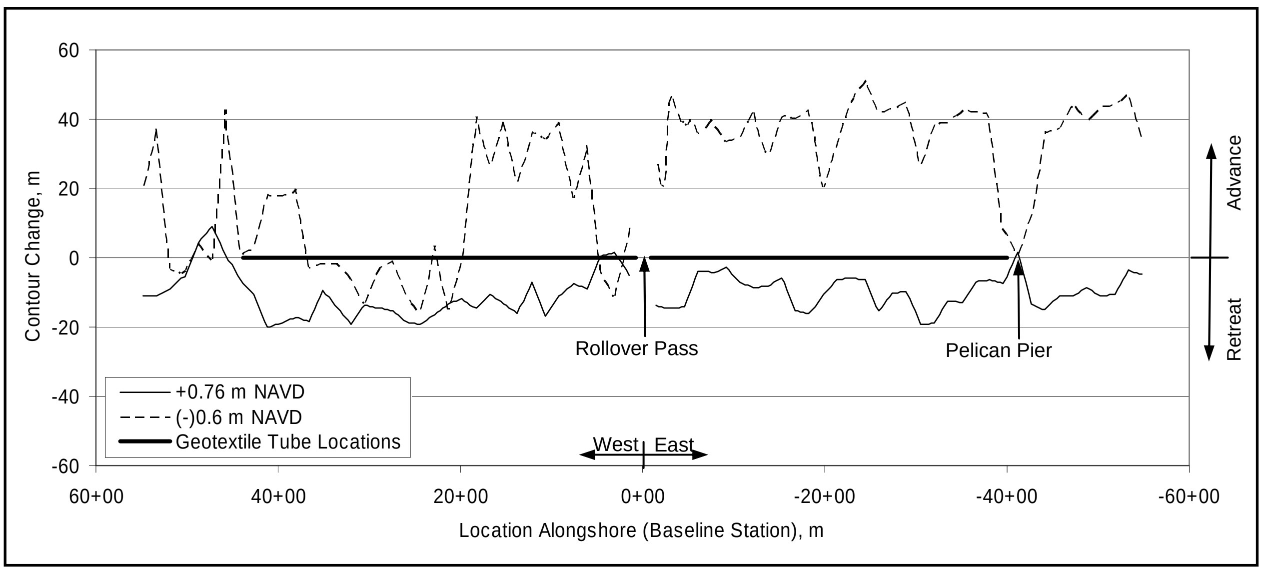

Figure 10. Contour changes at Bolivar Peninsula from HU Claudette (May 2003 to July 2003).

In addition to decreasing beach slope, HU Claudette caused localized scour depressions of as much as 0.6 m in front of portions of the GTs (Figures 11 and 12). Localized scour along the base of shore-parallel structures is common during storms. Scour areas are typically refilled during post-storm recovery as smaller and less steep waves transport sand back onshore. The scour was generally more continuous at Bolivar Peninsula and was clearly observable at many profiles both east and west of Rollover Pass.

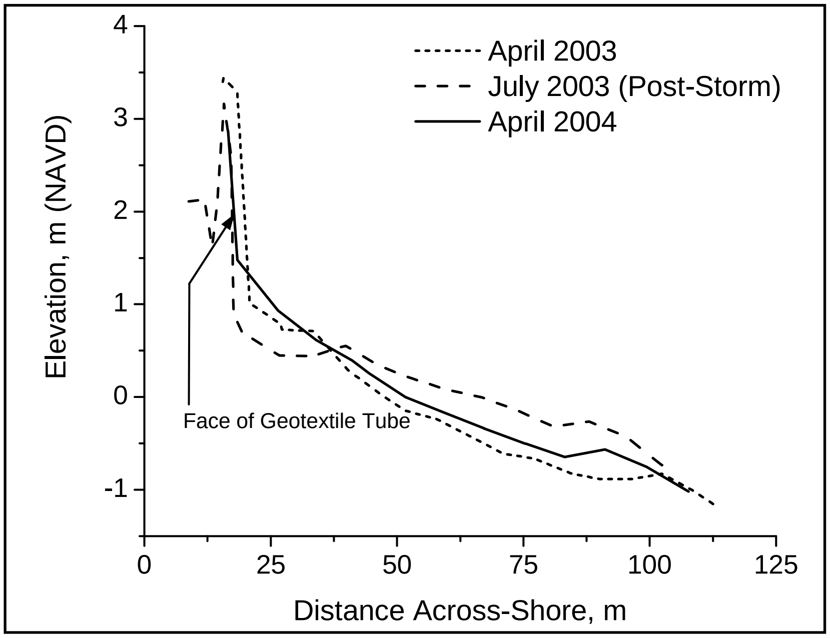

Figure 11. Typical beach profile scour and recovery at Galveston Island (beach with GT).

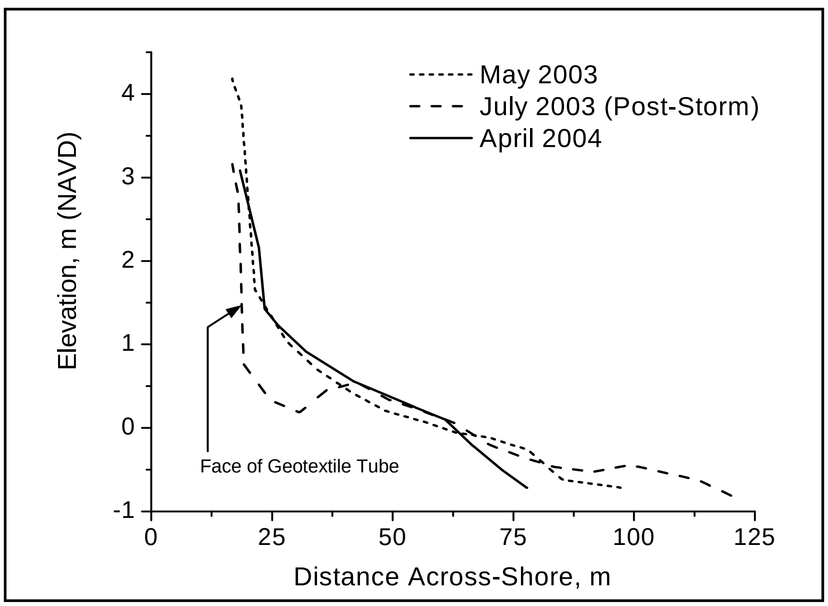

Figure 12. Typical beach profile scour and recovery at Bolivar Peninsula (beach with GT).

Post-Hurricane Recovery: Data collected in April 2004, approximately 9 months after HU Claudette, revealed that the beach berm and shoreface had experienced significant post-storm recovery, regardless of the presence of GTs. As shown in Figures 11 and 12, much of the sand that was transported offshore during the storm appears to have moved back onshore, refilling scour areas along GTs, partially restoring most profiles to their pre-storm condition. However, recovery of the exposed dunes and bluffs (which took place only at non-GT-protected areas) did

not occur. Figures 13 and 14 show the natural response of beach profiles not protected by GTs on Galveston Island and Bolivar Peninsula. The erosion caused by HU Claudette was still evident after 1 year. Recovery of the beach berm and shoreface is apparent by the recession of the lower contours and advance of the upper contours in Figures 15 and 16. Overall, the recovery of the beach appeared to be similar between GT and non-GT areas.

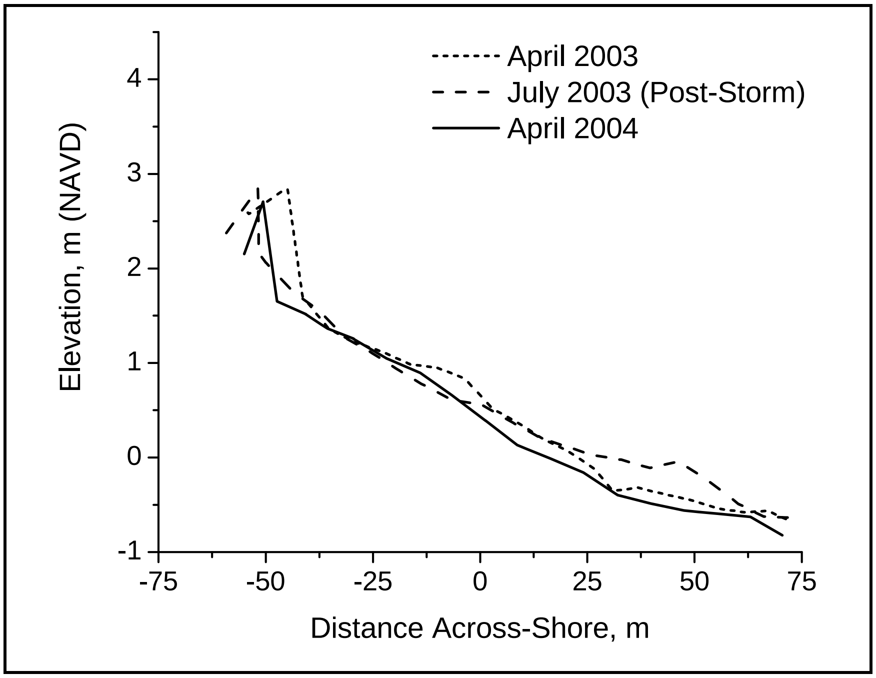

Figure 13. Typical beach profile at Galveston Island (beach without GT).

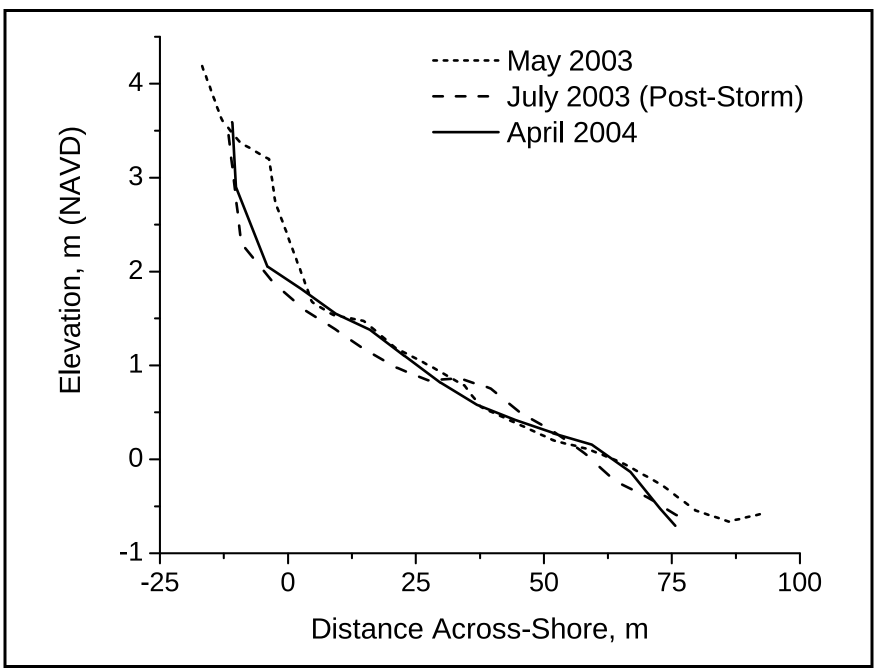

Figure 14. Typical beach profile at Bolivar Peninsula (beach without GT).

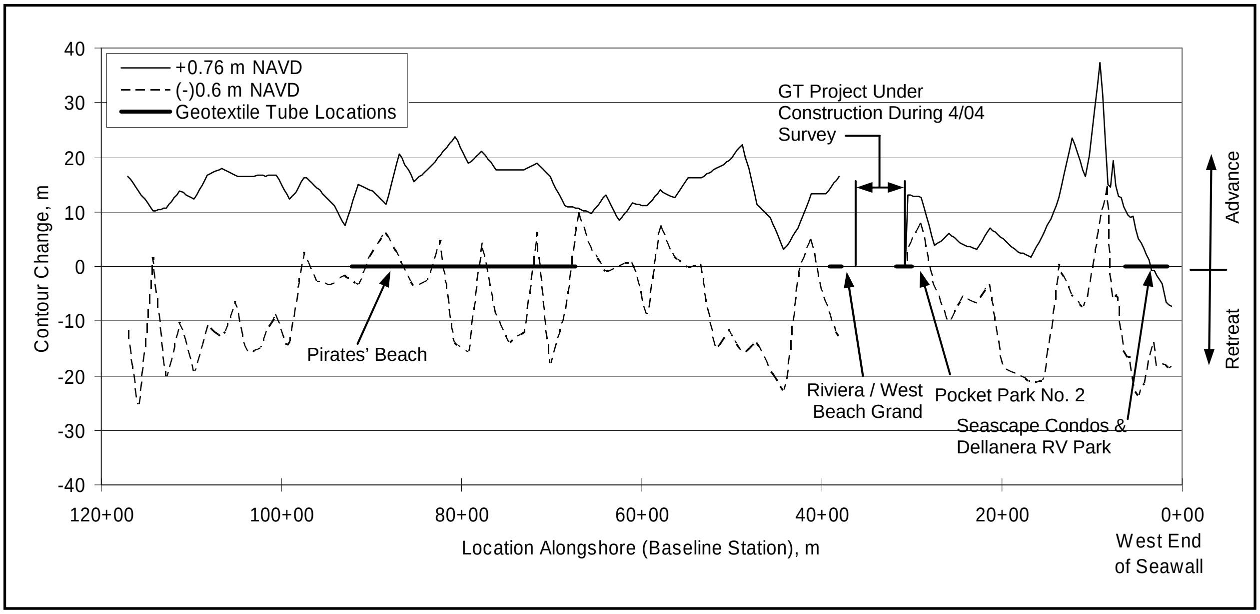

Figure 15. Post-HU Claudette contour changes at Galveston Island (July 2003 to April 2004).

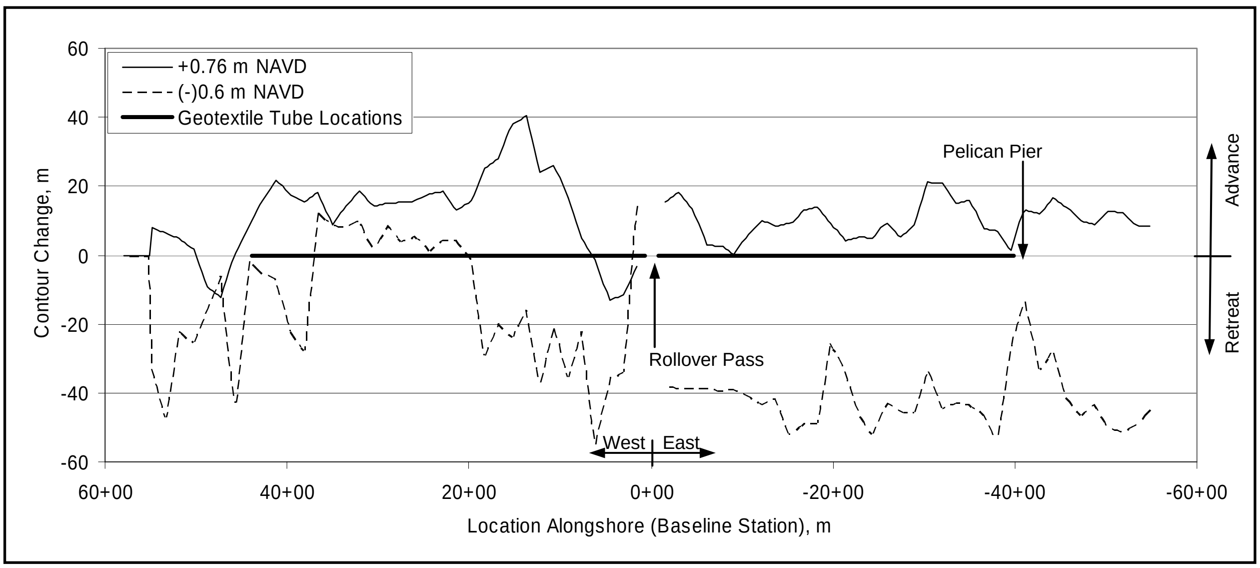

Figure 16. Post-HU Claudette contour changes at Bolivar Peninsula (July 2003 to April 2004).

Note that, at Galveston Island, the reach between sta 1+50 and 6+00 received approximately 20,000 m^3 of beach nourishment during the 9-month period after HU Claudette. Despite this nourishment, within approximately 300 m of the seawall, both the +0.76 m and -0.6 m contours receded. This recession may have been due to wave diffraction at the end of the Galveston Seawall and/or insufficient updrift (eastern) sand supply. Along the remainder of the Galveston Island monitoring shoreline, the GT and non-GT areas experienced similar trends in shoreline change and profile recovery.

Similar to Galveston Island, some of the post-Claudette recovery along Bolivar Peninsula is partially attributable to beach nourishment, with projects constructed east and west of Rollover Pass in February 2004. In particular, note the large advance of the +0.76 m contour that occurred west of the pass between sta 9+00 and 18+00, where approximately 80,000 m^3 of sand was placed. In contrast, note the recession of the +0.76 m contour that occurred within 600 m west of Rollover Pass. This recession is possibly caused by the inlet, as sand from the updrift beaches was transported through the inlet and/or offshore by tidal currents.

Protection to Upland Infrastructure: The protection provided by the GT core dunes to public infrastructure and other improvements landward of the dunes was clearly tested by HU Claudette. Table 2 summarizes a pre- and post-storm comparison of the +1.8 m NAVD contour (approximate dune/bluff line). Recession of dunes and bluffs was on average 30 to 50 percent greater for non-GT areas than GT areas, suggesting that the property and infrastructure landward of the GTs would have been damaged without the GTs. Despite failure of several short sections of the GTs and numerous punctures and tears, there was minimal damage to infrastructure. Most damage was limited to timber walkovers and drive-over ramps. Damage sustained by GTs has been repaired (Heilman and Hauske 2003) and has qualified for disaster recovery funding by the Federal Emergency Management Agency (FEMA), which recognizes the storm-damage reduction benefits provided by the projects.

Table 2
Dune/bluff Line Changes from Hurricane Claudette

	Average Recession of +1.8 m (NAVD) Contour	
	Galveston Island	Bolivar Peninsula
All locations	5.2	4.7
GT locations	3.4	3.6
Non-GT locations	6.1	7.7

Benefits of the GTs also include protection of the only evacuation routes for west Galveston Island and Bolivar Peninsula and the maintenance of a wider upland buffer for increased protection against surge and waves during future storms. Additional benefits have been a reduction in insurance claims resulting from damage caused by tropical storms and a subsequent rise in property values. The reduction in insurance claims was evident following TS Fay, HU Isidore, and HU Lili in September 2002. During this series of storms, the GTs provided the needed level of protection and are considered to have prevented the need for issuance of a Presidential Disaster Declaration in Galveston County.

CONCLUSIONS: As discussed by Griggs (2005), public opposition to shore-parallel structures on beaches is common because some people believe that the structures will necessarily accelerate erosion of the surrounding beaches. These perceptions and associated controversy also exist within factions of relevant professional communities, including the coastal engineering and coastal geology communities. The monitoring described in this note provides additional field data with which to resolve conflicting opinions regarding the interaction of shore-parallel structures and beaches.

In comparing beaches in Galveston County with and without GTs over approximately 8 years, no clear differences in shoreline change trends were observed. Similar magnitudes of erosion and accretion occurred for areas with and without GTs. Nourishment activities and severe storms appear to have been the primary influences on shoreline change. Other influences include sediment impoundment and/or downdrift erosion exacerbated by the Galveston Seawall and Rollover Pass.

Temporary localized scour occurred adjacent to the GTs during HU Claudette. However, the GTs did not cause sustained or permanent scour, and post-storm recovery was generally similar for beaches with and without GTs. The primary adverse impact of GTs on the beach appears to be the containment of sand behind the GTs and associated elimination of a partial supply of sand for downdrift beaches. The data collected over the 8-year monitoring period during which several beach and dune nourishment projects were completed suggests that this reduction in sand supply is insignificant. However, downdrift erosion may increase as ongoing erosion of adjacent non-GT beaches causes the GTs to encroach farther onto the beach. Degraded aesthetics and, as stated by Gibeaut et al. (2003), alteration of the natural geomorphology of the beach and dune system, and hindrance of the formation of coppice mounds and natural dunes might also occur.

Monitoring in Galveston County confirms that GTs can be a practical and relatively low-cost method of improving protection to coastal infrastructure without causing significant erosion of adjacent beaches. However, as applied in Galveston County, they are an interim method that should eventually be supplemented with more substantial countermeasures such as large-scale beach and dune creation and nourishment. In the meantime, periodic small-scale beach nourishment appears to be effective in helping maintain beach width seaward of the GTs.

The GTs have provided adequate protection to upland areas during storms. Damage to the GTs has been repairable and qualified for disaster recovery funding from FEMA. Additional benefits have included a reduction in insurance claims from tropical cyclones and an increase in property values. In evaluating the suitability of GTs for a given site and weighing the appeal of their relatively low cost, engineers should recognize that GTs may have limited life even with regular maintenance. Engineers should anticipate maintenance on at least an annual basis for GTs in moderate wave climates such as the Gulf of Mexico, and design thresholds may be limited to tropical storms or Category 1 hurricanes. GTs placed at sites that are subjected to frequent and rapid large-scale fluctuations in shoreline position, such as along an unstabilized tidal inlet, may be impossible to maintain for any useful duration.

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